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AUTHOR	Munby, Hugh
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ABSTRACT

This paper reviews the conceptual confusion surrounding the concept "scientific thinking" (also known as "the processes of science," "scientific processes," "inquiry skills," and sometimes, "the scientific method"). It begins with three separate arguments, each supporting a particular claim: (1) Science does not have exclusive rights to "scientific thinking." (2) "Scientific thinking," as usually portrayed, bears little relationship to how individuals actually think. (3) "Scientific thinking" is promoted in "methods" textbooks and in the science education literature. It is argued that the concept has attained an unwarrented status in the field of science education. If pre-service science teachers are to be assisted in their understanding of research, then they have to be confronted with the conceptual issues surrounding this concept. Anything less than this does a double disservice: it provides future teachers with a biased view of the potential of research, and it inhibits their growth as thoughtful professionals. (JN)

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EXPOSING THE MYTH OF SCIENTIFIC THINKING IN TEACHER EDUCATION PROGRAMS

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Hugh Munby

Faculty of Education
Queen's University
Kingston, Ontario

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ABSTRACT

This paper reviews the conceptual confusion surrounding the concept "scientific thinking" and argues that the concept has attained an unwarranted status in the field of science education. If pre-service science teachers are to be assisted in their understanding of research, then they have to be confronted with the conceptual issues surrounding this concept. Anything less than this does a double disservice: it provides future teachers with a biased view of the potential of research, and it inhibits their growth as thoughtful professionals.

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Introduction

The concern of this paper is for what is known variously as "scientific thinking," "the processes of science," "scientific processes," "inquiry skills," and, sometimes, "scientific method." All these, which here will be termed "scientific thinking," have become significant in science education and in the preparation of science teachers, as I show below. Normally, the popularity of any concept or approach in the literature of science education is no cause for agitation. But the case of "scientific thinking" is rather different, because the concept itself is problematical. And as a consequence, everything that we do with it in the name of teacher preparation becomes problematical. Indeed, there is a very real danger that talk about "scientific thinking" can mislead future teachers of science, thereby limiting their ability to reflect critically upon their own professional practice as well as upon the research literature that seems meant to inform their practice. This is why the present paper addresses improving science teacher education programs by inspecting basic concepts. The concept in question here is the concept of scientific thinking, and the argument is that it must be attended to thoroughly.

Two basic ideas are central to the argument that follows. The first is the notion that "scientific thinking" is a myth that says "Scientific thinking is the most powerful of all types of thinking available in the disciplines of knowledge. It is the way in which scientists do their work, and it is all there is to the intellectual work of science." The second is the view of professionalism that says "There is no professionalism without critical reflection, and critical reflection in science education demands a knowledgeable appraisal of the area's research, texts, and beliefs."

The paper begins with three separate arguments, each supporting a particular claim:

1. Science does not have exclusive rights to "scientific thinking."

2. "Scientific thinking," as usually portrayed, bears little relationship to how we actually think.

3. "Scientific thinking" is promoted in "methods" texts and in the science education research literature.

The final section of the paper returns to the opening theme of critical reflection, and makes the case for giving full attention to conceptual analysis in science teacher preparation programs.

Argument One: The Question of Exclusive Rights

The point of Argument One is to show that it is a mistake to think that what commonly passes as "scientific thinking" is the exclusive property of science. To be clear on this, it helps to begin by recording what "scientific thinking" is taken to mean, using pieces from the science education literature. Here, for example, is an item from the Psychological Corporation's Processes of Science Test (Biological Sciences Curriculum Study, 1962):

> Several similar rosebuds were selected for an experiment. Half the buds were placed in a liter of tap water; the other half were placed in a liter of similar tap water in which aspirin had been dissolved. The most general hypothesis the experiment was designed to test was that aspirin
>
> 1. will purify tap water.
> 2. has an effect on rosebuds.
> 3. improves the appearance of rosebuds.
> 4. has the same effect on water as do rosebuds.

I contend that this item is not measuring anything that is especially scientific; instead, it is asking a question not unlike some of the items in the Watson-Glaser Test of Critical Thinking. That is, it is measuring something about the respondent's ability to handle logic and general algorithms.

This is equally apparent in the following, which appear among a list of fallacies allegedly relevant to the study of inquiry in biology:

> Assuming that events that follow others are caused by them.
>
> Drawing conclusions on the basis of nonrepresentative instances.
>
> Drawing conclusions on the basis of very small and fortuitous differences. (Dreyfus & Jungwirth, 1980, pp. 310-311)

On the other side of the coin, Ross and Maynes (1983) introduce their test of experimental problem solving by acknowledging that the skills are not unique to science, although they suggest that the seven skills represent what successful scientists do. (I yearn to find out what unsuccessful ones do.) And, Arons' (1983) portrayal of scientific literacy includes being "aware of very close analogies between certain modes of thought in natural sciences and in other disciplines" (p.93). Despite these few counterinstances, the literature of science education seems to have gathered up "scientific thinking" as if it were the exclusive property of science and so of science education.

In some respects, this is not surprising. After all, it was the natural philosophers of three centuries ago who successfully overthrew Aristotelian philosophy and its categories of theoretical sciences (physics, mathematics, and metaphysics), practical sciences (ethics and politics), and productive sciences (the arts, carpentry, medicine, agriculture, etc.). For example, early in the

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seventeenth century, Bacon proposed new methods _and_ new categories in _Novum Organon_. But an explanation built from the history of philosophy is weak. The seemingly crystal-clear logic in Mill's _Philosophy of Scientific Method_ cannot explain our enchantment with "scientific thinking" because, as Nagel (1950) reminds us in introducing the text, "the development of the statistical view of nature during the second half of the nineteenth century cast doubt on his version of what constitutes the ideal of scientific investigation" (p. xlvi). All this, of course, is aside from the development of Kantian thought up to the current "received view" of the philosophy of science, which recognizes our role in constructing reality.

Possibly, we have been misled by language. The following reminds me of this form of seduction:

> The triads that correspond in French to our English "natural sciences, social sciences, and humanities" are _les sciences naturelles_, _les sciences sociales_, _et les sciences humaines_; and in German, _die Naturwissenschaften_, _die Sozialwissenschaften_, _und die Geisteswissenschaften_ (McCloskey, 1984, p.97)

The French _science_ and the German _wissenschaft_ connote disciplined study. In English, as McCloskey points out, it means this and much more: experimental work, quantification, etc., all of which suggest that science is very different from, say, history, or the explication of text, which is literary criticism. The English language appears to deny that such scholarly pursuits involve disciplined study.

How we got to the point of believing that "scientific thinking" belongs in science education is far less important than facing the arrogance of this view.

Argument Two: The Question of How We Think

I am not going to describe how we think; but I am going to argue that whatever "scientific thinking" is, _it_ doesn't describe how we think either. I do not want to touch the question of how scientists think, because I believe that the literature in philosophy of science has shown adequately that "scientific thinking" is not a plausible candidate. Instead, I want to find out what "scientific thinking" might be. The journey to the answer is short.

Somewhat buried in the literature is a fine paper by Daniels (1975), "What Is the Language of the Practical?" In this, the author attempts to uncover the ways in which psychological processes (as in "the cognitive process approach") are different from physical processes. I see this work as relevant because much of the language of "scientific thinking" corresponds to cognitive process language. Daniels argues:

> Our talk about mental processes has a logic very different from the logic of our talk about physical processes. Physical processes can be observed and identified independently of any product they may have; mental processes can be identified _only_ via their products. At least in principle, a physical process, such as baking or synapse-firing can be identified _as_ a process independently of what it produces. Of course, in some cases,

> it is extremely difficult, even physically impossible, to observe an ongoing process. But with mental processes we are not faced with difficulty or physical impossibility; we are faced with something more like logical impossibility. This is true, at least, of mental processes in people other than ourselves. (p.249)

As Daniels explains, we identify psychological processes by their products. So, when an inference appears, we suppose that something has been happening mentally. Then comes the awkward part. Because it is important for us to talk about these processes, we have to secure them in language by naming them. But they are not ostensible. "Showing and telling" won't work. So we invoke a rather elaborate ex post facto system and name the process after the word that describes the product. In this way, the process yielding an inference is "inferring," that yielding a comparison is "comparing," that giving a definition is "defining," and that resulting in an hypothesis is "hypothesizing." This language trick is enormously deceptive. I think we have been misled into thinking that because we can name these processes, they exist; and, we have come to think of them as existing as separate, identifiable processes that are thus capable of being isolated and developed by teaching.

What we have to recognize is that psychological processes and their counterparts in "scientific thinking" have meaning only because we can talk about them. This is precisely what Dewey was driving at when he wrote beneath "Logical Forms not Used in Actual Thinking, But to Set Forth Results of Thinking":

> In short, these forms apply not to reaching conclusions, not to arriving at beliefs and knowledge, but to the most effective way in which to set forth what has already been concluded, so as to convince others (or oneself if one wishes to call to mind its grounds) of the soundness of the result. In the thinking by which a conclusion is actually reached, observations are made that turn out to be aside from the point; false clues are followed; fruitless suggestions are entertained; superfluous moves are made. (Archambault, 1964, p.245)

The impact of Argument Two is as follows: Although we may attempt to focus instruction upon "scientific thinking," we can never in principle know that we are having any impact at all on the development of the psychological processes we believe should occur. This will always be true, even though we may use instruments to measure the products of this thinking. This is because the notion of "scientific thinking" cannot be known to bear any relationship to how we think.

Argument Three: "Scientific Thinking" Thrives

Argument Three is not a very substantial one, but it is important to show that "scientific thinking" is not a straw man, developed out of nothing in order to serve as this author's target. What is provided below shows that the notion of "scientific thinking" lives in the literature of science education and its research endeavors. (There is no attempt to cover the territory completely or to sample it scientifically.)

The "Test of Experimental Problem Solving," developed by Ross and Maynes (1983), is closely related to "scientific thinking" and is a recent arrival on the scene. Interestingly, it appears in the same issue of the Journal of Research in Science Teaching as a paper by Finley (1983) that shows the conceptual relationship of "science processes" to empiricism, and then argues that logical empiricism represents a fundamentally inadequate account of the nature of science! The "Test of Enquiry Skills" has been developed by Fraser (1980). Tobin and Capie (1982) have developed a group test of integrated science processes. A large number of earlier devices exist, as Mayer's (1974) review attests. Not only are the tests of these various versions of "scientific thinking" available, the research literature itself reports many examples of their use. Indeed, the area has now reached the point where its many studies have been subjected to meta-analysis (Steinkamp & Maehr, 1983).

Clearly, the idea of "scientific thinking" is alive and well, but it is not without its detractors. Kyle (1980) contends:

> The time has come for science educators to limit the use of the term "scientific inquiry" to that which constitutes scientific inquiry from the scientist's point of view. By placing proper constraints on what constitutes scientific inquiry, the many other descriptors of science education will be able to reflect more accurately what is really happening in the science classroom and laboratory. (p.128)

"Scientific thinking" is promoted in some so-called methods texts for beginning science teachers. For example, Trowbridge, Bybee and Sund (1981) present a very orthodox empiricist view in a section that distinguishes between discovery and inquiry strategies (p.168), even though an earlier chapter attempts to give equal consideration to "deductive," "inductive," and "conjecture and refutation" models of the nature of science. Simpson and Anderson (1981) open their text with an account of scientific literacy that, among other things, involves the use of "the processes of science in solving problems, making decisions" and includes understanding the nature of science (p. 6). Similarly, Collette and Chiapetta (1984) present a clear account of "scientific thinking" in their first chapter. Here, six clear steps are presented, with the caution that "research scientists do not necessarily follow this step by step procedure nor do they follow any absolute number of steps to solve problems (p.8).

There follows an account of science that leaves this reader with the thought that scholars in other disciplines do not generate hypotheses, nor test hypotheses against data. This chapter's summary is also misleading:

> Science is also a way of thinking. Approaches to obtaining information have changed greatly through the centuries, from the tight logic and deductive procedures to empiricism and inductive procedures, and from the search for nature's laws in the past century to the search for statistical probabilities in this century (p.23)

(The terms "statistics" and "probability" do not appear in the text's index or table of contents.) Later still, the reader is informed that observing, classifying, inferring, predicting, hypothesizing, and interpreting are among the thirteen "thinking processes that are associated with science" (p.71). These few examples show that the idea of "scientific thinking" is present in methods texts and even emerges in rather confused ways.

Conceptual Analysis and Critical Reflection

I have argued that the notion of "scientific thinking" and what it subsumes is problematical. That is, it is not straightforwardly the case that "scientific thinking" is central to science and to science education, nor that the concept speaks adequately to how a scientist or anyone else thinks. These are the grounds for finding that the concept "scientific thinking" is problematical, and because the concept is used in science education, it is a problematical educational concept too.

The realization that an educational concept is problematical has important consequences for teacher preparation. If the intent of professional preparation is to equip students with the means to be able to act with thoughtful autonomy, then it has to follow that programs must present the problems of the field and not pass these over. If the problems are not addressed, the opportunity for students to be autonomous is necessarily truncated. As Hawkins (1983) observed of teaching in a different setting, the danger is that "they might uncritically accept the errors that adults so often uncritically impose" (p.73).

Professional autonomy is linked to a critical reflection upon professional practice. And, for pre-service science teachers to begin to reflect critically, they must learn to interpret all that they read, see, and hear, both in college courses and in practice-teaching experiences. This is true of the curriculum materials such students read and use, just as it is true of the research that they encounter.

It is one thing to use research results in teacher education programs; it is quite another to make it possible for pre-service teachers to learn how to make critical assessments of that research. Yet, if pre-service education is to meet the goal of fostering autonomy, then its graduates must be able to reflect critically upon research that they might encounter during their professional years. Such reflection requires a minimal understanding of research techniques, but that is not all. Critical reflection also involves raising questions about the conceptual basis of the research, and this suggests that teacher education programs need to include opportunities for pre-service candidates to consider the results of alternative research, especially research that is critical of standard and fundamental conceptualizations.

Conceptual analysis, as used in Argument One and in other places (for example, Munby & Russell, 1983) is a powerful technique for revealing the assumptions underlying the central concepts of an area. This paper illustrates the dangers of an uncritical acceptance of the meaning of "scientific thinking," and proposes that conceptual analysis is a significant part of any curriculum that intends to develop the critical reflection of science teachers.

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